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(54) Hydraulically actuated semiconductor wafer clamping and cooling apparatus

(57) Apparatus for hydraulically clamping a semiconductor wafer 8 in a vacuum chamber during ion beam processing includes a compression plate 12 attached to a housing 14 and a movable pressure plate 18 coupled by a fluid-containing bellows 20 to the housing. When a predetermined pressure is applied to the fluid, the bellows 20 expands and causes the wafer 8 to be firmly clamped against the compression plate 12. A pliable, thermally conductive pad 16 between the wafer and the pressure plate facilitates transfer of thermal energy from the wafer to the pressure plate. The fluid is circulated through a heat exchanger and the bellows to provide efficient cooling of the pressure plate.

FIG.2

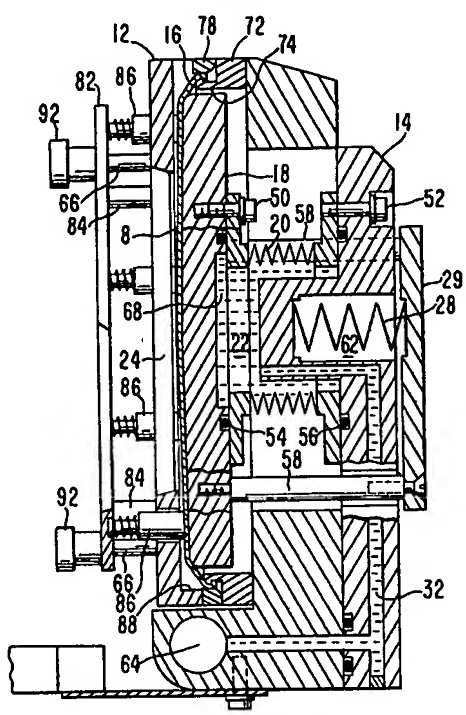

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FIG.1

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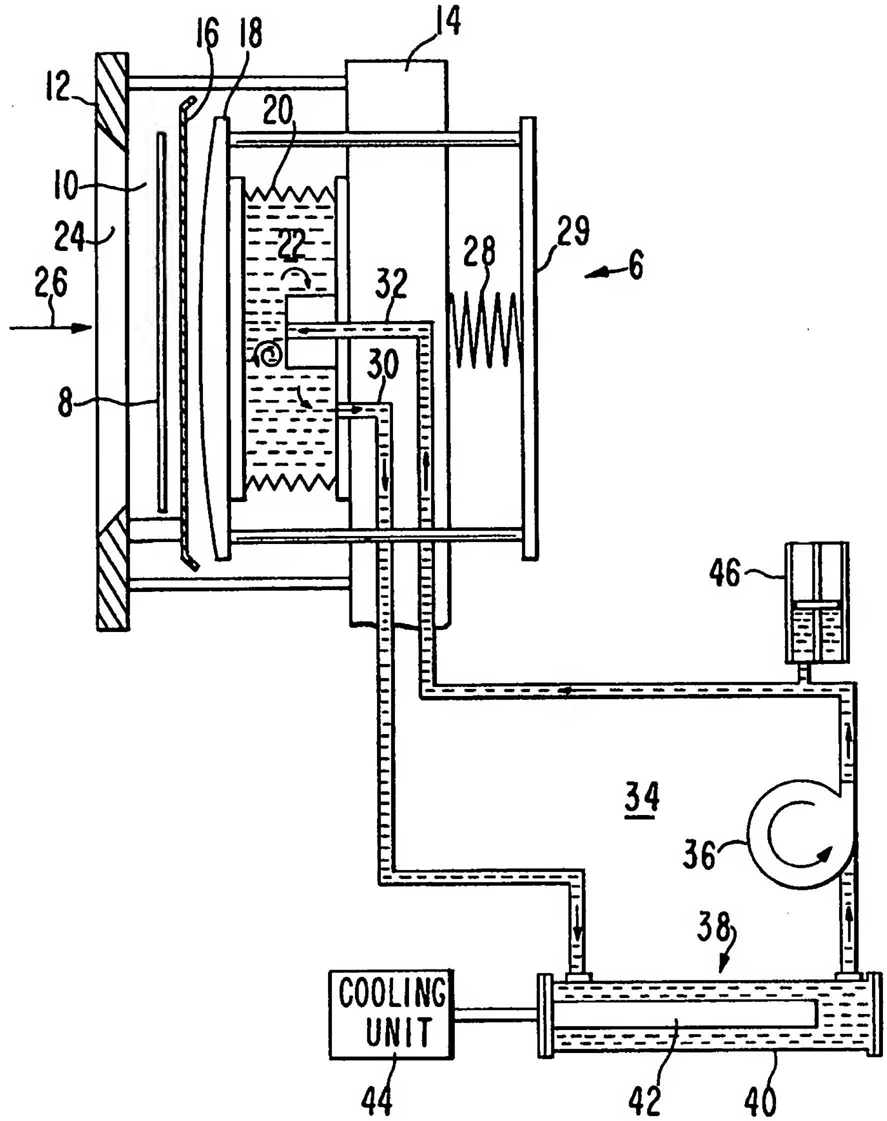

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FIG.2

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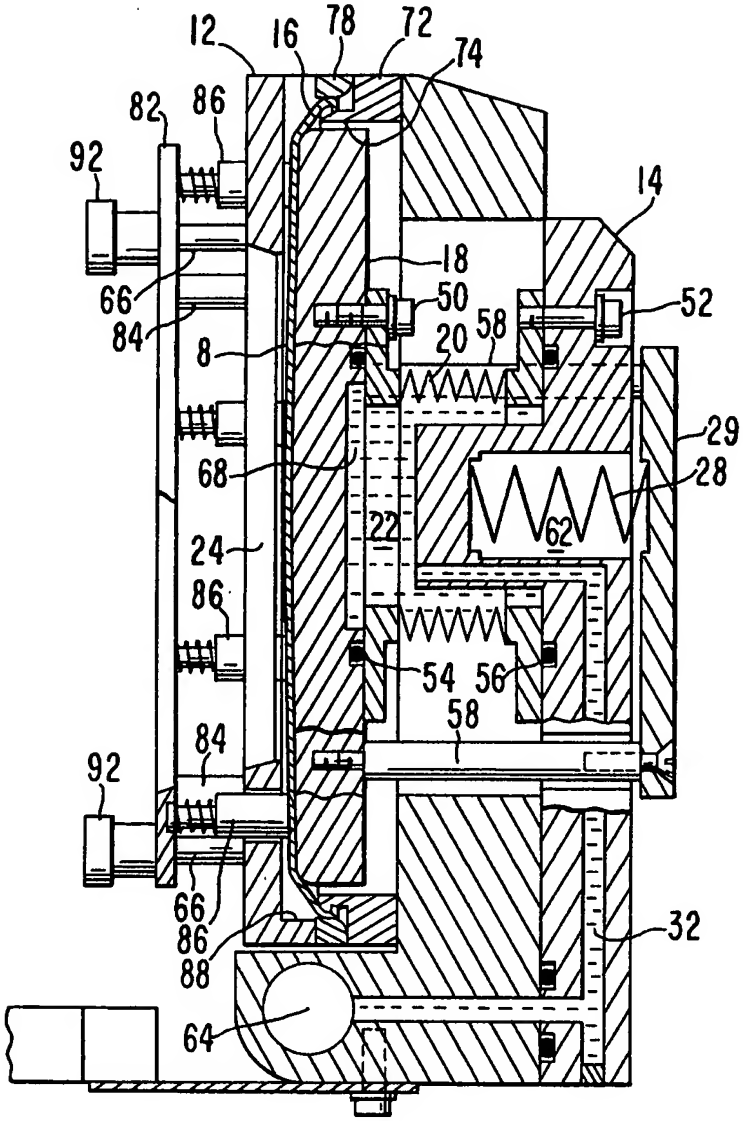

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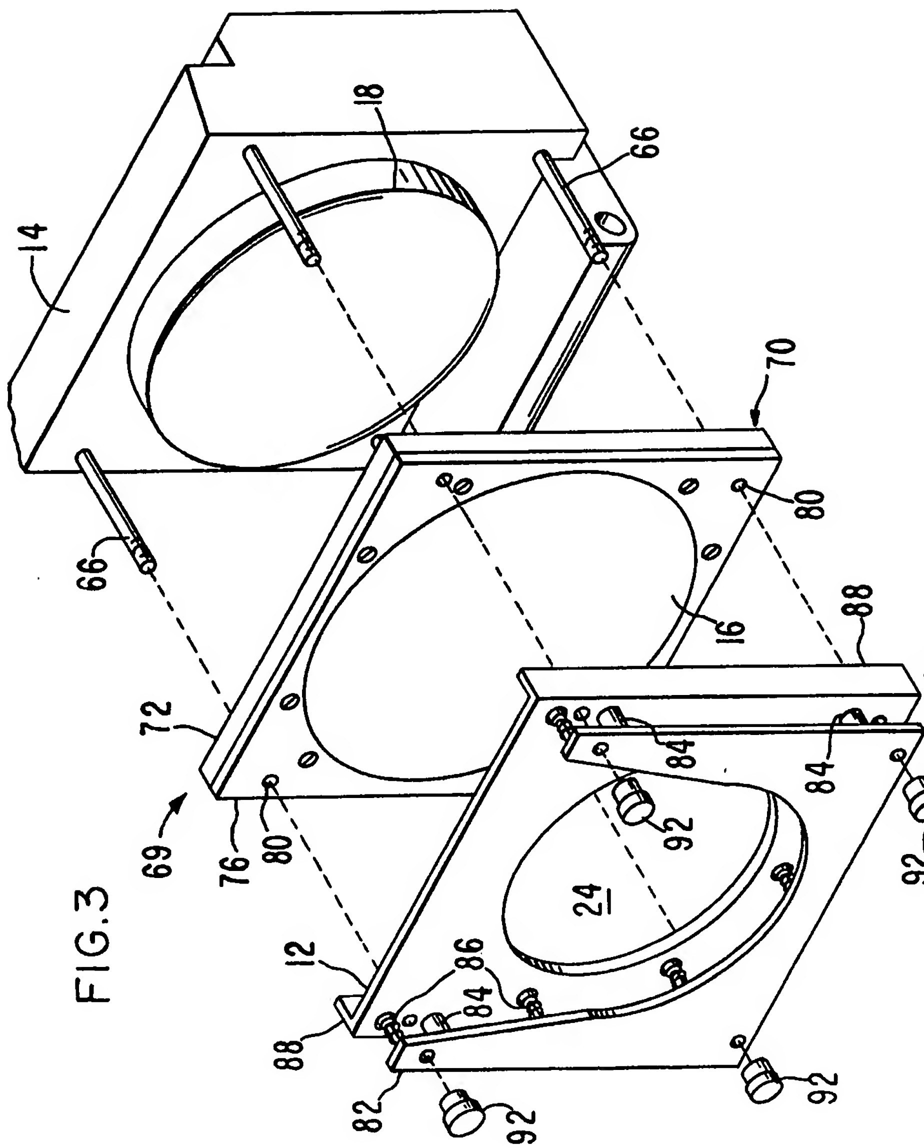

FIG.3

SPECIFICATION

Hydraulically actuated semiconductor wafer clamping apparatus

This invention relates to apparatus for clamping a semiconductor wafer in a vacuum chamber during processing thereof and, more particularly, relates to hydraulically actuated wafer clamping apparatus which provides effective wafer cooling.

In the processing of semiconductor wafers, it is sometimes necessary to subject the wafers to elevated temperatures. For the diffusion of impurities, the growth of epitaxial layers, the annealing of metal-semiconductor contacts, and the like, such elevated temperatures are desirable. However, at many points in processing it is undesirable to expose the wafer to elevated temperatures since uncontrolled diffusion of impurities beyond prescribed limits, as well as the segregation of impurities at epitaxial interfaces, will occur.

Semiconductor wafers are frequently coated before processing with a patterned layer of photoresist material. For example, in ion implantation, the photoresist defines the pattern of implanted impurities. Commonly used photoresist materials have relatively low melting points. If the photoresist melting point is exceeded during processing, the pattern is degraded or completely destroyed. Thus, it is desirable to expose semiconductor wafers to elevated temperatures only when a process step positively requires it and, if necessary, to provide cooling of the wafer in order to prevent elevated temperatures from being attained.

In the fabrication of integrated circuits, a number of processes have been established which involve the application of high energy beams onto silicon wafers. These processes include ion implantation, ion beam milling and reactive ion etching. In each instance, a beam of ions is generated in a source and directed with varying degrees of acceleration toward a target. Ion implantation has become a standard technique for introducing impurities into semiconductor wafers. Impurities are introduced into the bulk of semiconductor wafers by using the momentum of energetic ions as a means of embedding them in the crystalline lattice of the semiconductor material.

As energetic ions impinge on a semiconductor wafer and travel into the bulk, heat is generated by the atomic collisions. This heat can become significant as the energy level or current level of the ion beam is increased.

In commeerial semiconductor processing one of the major objectives is to achieve a high throughput in terms of wafers processed per unit time. One of the ways to achieve high throughput in an ion beam system is to use a relatively high power beam. Large amounts of heat may thus be generated. As noted hereinabove, this heat is undesirable.

As a consequence, most industrial equipment which is capable of producing high beam power processes wafers in a batch in order to spread the incident power over a large area and to reduce the heating in any given target. A batch processing system involving mechanical movements of the wafers during implantation is disclosed in U.S. Patent No. 3,778,626 issued December 11, 1973 to Robertson. Batch processing systems are generally large to accommodate the batches and are generally used only for high dose implantations. In addition, throughput is less than optimum because of the time required to manually change batches.

Reduction of heating by alternate scanning of targets is disclosed in pending application Serial No. 306,056, filed September 28, 1981, and assigned to the assignee of the present invention.

Conductive cooling has also been used to alleviate the problem of wafer heating. For example, wafers are placed in thermal contact with cooled metal platens. Another approach has been to introduce a gas behind a wafer in order to permit conduction between the backside of the wafer and the cooled support surface as disclosed in U.S. Patent No. 4,261,762, issued April 14, 1981, to King. Centrifugal forces have also been used to press wafers against cooled surfaces as disclosed in pending application Serial No. 284,915, filed July 20, 1981, and assigned to the assignee of the present invention.

Wafers have been pressed against pliable thermally conductive polymers to enhance thermal contact as disclosed in U.S. Patent No. 4,282,924, issued August 11, 1981, to Faratra. A clamping ring actuated by cams presses a semiconductor wafer against a convexly curved platen which has a pliable, thermally conductive material adhered to its surface. The platen is cooled by circulating freon through a cavity in the housing.

In any case of conductive cooling, the objective is to provide intimate contact between the wafer and the cooled surface. Since the wafer is processed in a high vacuum, any space between the wafer and the cooled surface eliminates the possibility of conductive cooling. Surface irregularities in the semiconductor wafer make this intimate contact difficult to achieve in practice.

Prior art approaches have generally required elaborate hardware and do not always provide the desired level of cooling. In particular, mechanical clamping mechanisms are relatively complex, causing servicing to be difficult and time consuming. Furthermove, mechanical tolerances and wear can result in nonuniform or reduced wafer clamping pressure which, in turn, reduces the thermal conductivity between the wafer and the cooled surface.

It is an object of the present invention to provide new and improved apparatus for clamping a semiconductor wafer in a vacuum chamber.

It is another object of the present invention to provide apparatus for efficient cooling of a semiconductor wafer in a vacuum chamber during processing.

It is yet another object of the present invention to provide apparatus for hydraulically clamping a semiconductor wafer against a pliable, thermally conductive pad so as to provide rapid transfer of thermal energy.

According to the present invention, these and other objects and advantages are achieved in an apparatus for clamping a semiconductor wafer in a

vacuum chamber. The apparatus comprises a housing, a compression plate coupled to said housing and adapted to engage the wafer, and a pressure plate in movable relationship with the compression plate. The pressure plate is adapted for movement between a retracted position, in which the compression plate and the pressure plate define a wafer receiving slot, and a wafer-clamping position, in which the pressure plate causes the wafer to be firmly clamped against the compression plate. The apparatus further comprises a fluid-containing member coupled between the housing and the pressure plate. The member contains a fluid which, in response to application of a predetermined pressure thereto, causes actuation of the member and movement of the pressure plate to the wafer-clamping position. The apparatus further includes means for applying the predetermined pressure to the fluid when movement of the pressure plate to the wafer-clamping position is desired and means for retracting the pressure plate to the retracted position upon removal of the predetermined pressure from the fluid.

According to another aspect of the invention, the above-described apparatus can include means for cooling the fluid which actuates the pressure plate and a pliable, thermally conductive pad positioned between the pressure plate and the wafer. Thermal energy is transferred from the wafer through the thermally conductive pad and the pressure plate to the fluid.

For a better understanding of the present invention together with other and further objects, advantages and capabilities thereof, reference may be had to the accompanying drawings which are incorporated herein by reference and in which:

Fig. 1 is a simplified schematic diagram illustrating the apparatus of the present invention;

Fig. 2 is a cross-sectional view of a wafer clamping and cooling apparatus according to one embodiment of the present invention; and

Fig. 3 is an exploded perspective view of the wafer-clamping and cooling apparatus shown in Fig. 2.

An apparatus for clamping a semiconductor wafer in a vacuum chamber and for providing cooling of the wafer during processing is shown in schematic form in Fig. 1. In a platen assembly 6, a semiconductor wafer 8 is positioned in a wafer-receiving slot 10 between a compression plate 12, which is coupled to a housing 14, and a pliable, thermally conductive pad 16. A pressure plate 18 is coupled to the housing 14, in movable relationship with the compression plate 12, by a bellows 20. The bellows 20 contains a fluid 22 which, in response to application of a predetermined clamping pressure thereto, causes expansion of the bellows 20 and movement of the pressure plate 18 from a retracted position (shown in Fig. 1) to a wafer-clamping position (not shown in Fig. 1). In the wafer-clamping position, the pressure plate 18 firmly clamps the wafer 8 and the thermally conductive pad 16 against the compression plate 12. The compression plate 12 includes an aperture 24 which exposes the front side of the wafer 8 to an ion beam 26. The wafer 8 is clamped at its circumferential edge by the periphery of the aperture 24. A retraction spring 28 is coupled between the housing 14 and a retraction plate 29 which in turn is coupled to the pressure plate 18. The retraction spring 28 causes retraction of the pressure plate 18 to its retracted position when the predetermined clamping pressure is removed.

The housing 14 includes fluid passages 30, 32 which couple the fluid 22 in the bellows 20 to a fluid system 34. The fluid system 34 is a closed loop system which operates to cool the fluid 22 and to actuate the bellows 20. A pump 36 and a heat exchanger 38 are coupled in series and are coupled to the fluid passages 30, 32 by appropriate fluid couplings. The pump 36, which can be a gear pump or centrifugal pump, circulates the fluid 22 through the bellows 20 and the heat exchanger 38 at a rate of about one gallon per minute. The heat exchanger 38 can be of the type in which the fluid 22 passes through a barrel 40 containing a refrigerated probe 42. The probe 42 contains a material which is cooled by a cooling unit 44. These and other suitable heat exchangers are known in the art. An air-over-fluid accumulator 46 coupled to the fluid system 34 causes an increase in the fluid pressure and actuation of the bellows 20 when increased air pressure is applied to the input.

The fluid 22 should have a low freezing point and should be easy to pump through the fluid system 34 and the bellows 20. In addition, the fluid 22 should be compatible with the materials of the apparatus, such as O-rings, and should have a high dielectric constant since the pressure plate 18 is frequently part of an electrical circuit for measuring dosage. One preferred fluid is methanol.

The platen assembly 6 is shown in more detail in Figs. 2 and 3. The bellows 20 is attached to the rear of the circular pressure plate 18 and to the housing 14 by appropriate mounting screws 50, 52. O-rings 54, 56 provide a vacuum-tight seal between the fluid 22 and the external vacuum environment. The bellows 20 can be any sufficiently flexible bellows of suitable dimension and capable of withstanding the pressure differential between the vacuum environment and the fluid 22. A preferred bellows material is stainless steel. Connecting pins 58 are coupled to the rear of the pressure plate 18, pass through holes in the housing 14 and are coupled to the retraction plate 29 at the rear of the housing 14. The retraction spring 28 is positioned in a recess 62 in the housing 14 so as to bear against the retraction plate 29. The fluid passages 32 and 30 (not shown) provide a fluid coupling between the bellows 20 and the fluid system 34 through the housing 14. The platen assembly 6 is mounted for rotary movement about on axis 64. The fluid passages 30, 32 connect to rotary fluid couplings on the axis 64. A plurality of mounting pins 66 extend frontwardly from the housing 14.

The pressure plate 18 is generally disc-shaped with a convexly curved front surface to provide intimate thermal contact with the wafer. A recess 68 for receiving fluid 22 can be provided on the rear surface of the pressure plate 18.

A pad assembly 69 (Fig. 3) includes the thermally

conductive pad 16 and a pad holder 70. The pad holder 70 grips the pad 16 around its periphery and includes a first element 72 with an inner ring 74 (Fig. 2) and a second element 76 with an outer ring 78. When the elements 72 and 76 are connected together, the inner ring 74 and the outer ring 78 constitute concentric rings which grip the pad 16 therebetween. The pad holder 70 includes holes 80 corresponding with the positions of the mounting pins 66 on the housing 14.

It has been found that superior thermal transfer properties are provided when the pad 16 is a thermally conductive rubber, that is, rubber impregnated with a thermally conductive material. A pad 16 having a thickness in the range between 0.08 cm and 0.18 cm, preferably 0.16 cm, and a durometer between 40 and 60 has been found suitable. The durometer number is a measure of rubber hardness with high numbers indicating greater hardness. Prior art thermally conductive pads have been thinner and harder. The material which affords the rubber its thermally conductive properties must be a material which does not react with or otherwise adversely affect the semiconductor wafer. Preferred rubber additive materials for use with silicon wafers are beryllium and aluminum.

A compression plate assembly 81 includes the compression plate 12, a shield 82 mounted frontwardly of the compression plate 12 on standoffs 84, and a plurality of spring-loaded bumpers 86 attached to the shield 82 and extending through holes in the compression plate 12. The compression plate 12 includes a rearwardly projecting lip 88 along the bottom edge and both side edges thereof. The aperture 24, slightly smaller in diameter than the semiconductor wafer to be processed, is provided in the compression plate 12. The shield 82 is shaped so that no part of the aperture 24 is blocked by the shield 82. The function of the shield 82 is to absorb ion beam energy which would otherwise be absorbed by the compression plate 12 and cause additional heating of the wafer 8. The compression plate 12 and the shield 82 each include aligned holes corresponding with the positions of the mounting pins 66 on the housing 14.

The pad assembly 69 and the compression plate assembly 81 are mounted on the housing 14 with the mounting pins 66 extending through the holes 80 in the pad holder 70 and through the holes in the compression plate 12 and the shield 82. Thumbscrews 92, attached to the mounting pins 66, secure the pad assembly 69 and the compression plate assembly 81 to the housing 14. When the pad assembly 69 and the compression plate assembly 81 are thus mounted, the spring - loaded bumpers 86 bear against the front surface of the thermally conductive pad 16.

In operation, the pressure plate 18 is initially in its retracted position with its rear surface bearing against the housing 14. The pad 16 conforms to the convexly curved front surface of the pressure plate 18. The wafer-receiving slot 10 is thus defined between the compression plate 12 and the pad 16. The wafer - receiving slot 10 is further defined by the spring loaded bumpers 86 which guide the wafer 8 and retain it in a position directly behind the aperture 24. The wafer 8 is introduced into the wafer - receiving slot 10 by gravity after rotation of the platen assembly 6 to a wafer - receiving position, as described generally in U.S. Patent No. 4,282,924.

After the wafer is in position and the platen assembly 6 is returned to the upright position, the pressure plate 18 is moved to its wafer - clamping position, as illustrated in Fig. 2, by increasing the air pressure applied to the accumulator 46. This in turn causes an increase in pressure in the fluid system 34 and the bellows 20 and expansion of the bellows 20. The pressure plate 18 slightly stretches and pad 16 and clamps the wafer 8 firmly against the compression plate 12. Since the aperture 24 is smaller than the diameter of the wafer 8, the same is clamped at its circumferential edge. It will be realized that compression plates with different size apertures are used with wafers of different sizes in order that most of the wafer surface be exposed to the ion beam 26. In the wafer - clamping position, the thermally conductive pad 16 is in intimate contact with both the wafer 8 and the pressure plate 18. Thus, thermal energy imparted to the wafer 8 by the ion beam 26 is provided with a high thermal conductivity path through the pad 16 and the pressure plate 18 to the fluid 22 contained within the bellows 20. Since the fluid 22 is continuously cooled and circulated through the bellows 20, as described hereinabove, thermal energy is removed from the platen assembly.

The bellows 20 not only provides linear motion of the pressure plate 18 but also, because of the inherently flexible nature of the bellows 20, can provide small angular movements of the pressure plate 18 to compensate for tolerances in the remainder of the platen assembly and achieve uniform clamping pressure on the wafer. As noted above, more uniform clamping pressure results in better wafer cooling performance.

After ion beam processing of the wafer 8, the air pressure applied to the accumulator 46 is reduced, thus reducing the fluid pressure in the bellows 20. The retraction spring 28 has sufficient force to overcome the reduced fluid pressure and cause compression of the bellows 20 and movement of the pressure plate 18 to its retracted position. The wafer 8 is removed from the wafer - receiving slot 10 by rotation of the platen assembly 6 to a wafer - ejecting position, as described generally in U.S. Patent No. 4,282,924, thus completing the wafer processing cycle. No wafer ejecting mechanism is required.

As noted hereinabove, maintaining a high level of throughput is of great importance in commercial semiconductor processing. Throughput is enhanced by minimizing machine down-time for servicing or for other reasons. The platen assembly 6 shown in Figs. 1 - 3 and described hereinabove has a construction which facilitates servicing. The two most frequently performed service functions are; 1) replacement of the thermally conductive pad 16, and 2) changing the compression plate 12 to accommodate different size wafers. Either or both of these functions can be performed by removing the thumbscrews 92 and removing the compression plate

assembly 81 and, if necessary, the pad 81 assembly from the mounting pins 66. The new units are mounted and the thumbscrews 92 are placed.

The wafer cooling performance of the apparatus shown in Figs. 1-3 and described hereinabove was measured in an ion implantation system utilizing a thermocouple bonded to the front surface of the wafer. A 100 millimeter diameter wafer was implanted with 180 KeV As^+ ions. The fluid in the wafer clamping system was maintained at a temperature of −25°C and a fluid pressure of 345 kN/m^2 was used to overcome the force of the retraction spring and clamp the wafer. At an imput ion beam power level of 1.0 watt per square centimeter, the wafer reached an equilibrium temperature of +28°C; at an input power level of 2.0 watts per square centimeter, the wafer reached an equilibrium temperature of +69°C. Thus, the temperature rise over the initial temperature of −25°C is approximately 50°C/watt/cm^2. Since the maximum temperature of resist-coated wafers is about 135°C, the apparatus of the present invention permits operation over a wide range of input power levels.

Thus, there is provided by the present invention apparatus for clamping a semiconductor wafer in a vacuum chamber and for cooling the wafer when ion beam power is applied thereto. The hydraulically actuated pressure plate provides uniform wafer clamping pressure. The circulation of the cooled fluid through the bellows provides efficient removal of thermal energy from the pressure plate and wafer. The construction of the apparatus facilitates servicing.

While there has been shown and described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the scope of the invention as defined by the appended claims.

CLAIMS

1. Apparatus for clamping a semiconductor wafer in a vacuum chamber during processing thereof, said apparatus comprising:

a housing;

a compression plate coupled to said housing and adapted to engage said semiconductor wafer;

a pressure plate, in movable relationship with said compression plate, adapted for movement between a retracted position, in which said compression plate and said pressure plate define a wafer-receiving slot, and a wafer-clamping position in which said pressure plate causes said wafer to be firmly clamped against said compression plate;

a fluid-containing member coupled between said housing and said pressure plate, said member containing a fluid which, in response to application of a predetermined pressure thereto, causes actuation of said member and movement of said pressure plate from said retracted position to said wafer-clamping position;

means for applying said predeterined pressure to said fluid when movement of said pressure plate to said wafer-clamping position is desired; and

means for retracting said pressure plate to said retracted position upon removal of said predetermined pressure from said fluid.

2. The apparatus as defined in claim 1 wherein said fluid-containing member includes a bellows which expands upon application of said predetermined pressure, causing said pressure plate to move in the direction of said compression plate.

3. The apparatus as defined in claim 2 further including a pliable, thermally conductive pad positioned between said pressure plate and said wafer so as to provide thermal conduction therebetween when said pressure plate is in said wafer-clamping position.

4. The apparatus as defined in claim 3 wherein said compression plate engages the front side of said wafer at its circumferential edge and said pressure plate presses said thermally conductive pad against the back side of said wafer in said wafer-clamping position.

5. The apparatus as defined in claim 2 wherein said means for applying said predetermined pressure includes a fluid passage through said housing to said bellows adapted for coupling to a pressure source.

6. The apparatus as defined in claim 5 wherein said means for retracting said pressure plate includes a retraction spring coupled between said housing and said pressure plate.

7. The apparatus as defined in claim 6 wherein said fluid comprises methanol.

8. Apparatus for clamping a semiconductor wafer in a vacuum chamber and for providing cooling of said wafer during processing thereof, said apparatus comprising:

a housing;

a compression plate coupled to said housing and adapted to engage said semiconductor wafer;

a pressure plate, in movable relationship with said compression plate, adapted for movement between a retracted position, in which said compression plate and said pressure plate define a wafer-receiving slot, and a wafer-clamping position, in which said pressure plate causes said wafer to be firmly clamped against said compression plate;

a pliable, thermally conductive pad positioned between said pressure plate and said wafer so as to provide thermal conduction therebetween when said pressure plate is in said wafer-clamping position;

a bellows coupled between said housing and said pressure plate, said bellows containing a fluid which, upon application of a predetermined pressure thereto, causes actuation of said bellows and movement of said pressure plate from said retracted position to said wafer-clamping position and which is in thermal contact with said pressure plate;

means for applying said predetermined pressure to said fluid when movement of said pressure plate to said wafer-clamping position is desired;

means for cooling said fluid; and

means for retracting said pressure plate to said retracted position upon removal of said predetermined pressure from said fluid,

whereby thermal energy is transferred from said wafer through said pad and said pressure plate to said fluid.

9. The apparatus as defined in claim 8 wherein said compression plate engages the front side of said wafer at its circumferential edge and said pressure plate presses said thermally conductive pad against the back side of said wafer in said wafer-clamping position.

10. The apparatus as defined in claim 9 wherein said means for cooling said fluid includes a pump and a heat exchanger coupled to said bellows in a closed - loop system, said pump being operative to circulate said fluid through said closed - loop system, including said bellows, and said heat exchanger being operative to remove thermal energy from said fluid.

11. The apparatus as defined in claim 10 wherein said heat exchanger includes a fluid chamber with a refrigerated probe located therein.

12. The apparatus as defined in claim 10 wherein said means for applying said predetermined pressure includes an air - over - fluid accumulator coupled to said bellows.

13. The apparatus as defined in claim 12 wherein said fluid comprises methanol.

14. The apparatus as defined in claim 9 wherein said thermally conductive pad is at least .03 inch in thickness.

15. The apparatus as defined in claim 14 wherein said thermally conductive pad comprises rubber containing a thermally conductive material.

16. The apparatus as defined in claim 15 wherein said thermally conductive pad comprises rubber containing beryllium.

17. The apparatus as defined in claim 9 wherein said compression plate includes an aperture therethrough slightly smaller in dimension than said wafer and said pressure plate includes a convexly curved front surface which clamps said wafer at its circumferential edge against the periphery of said aperture in said wafer - clamping position and wherein said pressure plate is coupled at its rear surface, directly behind said wafer, to said bellows.

18. The apparatus as defined in claim 17 further including bumpers for positioning said wafer relative to said aperture in said wafer - receiving slot.

19. Apparatus for providing cooling for a semiconductor wafer during implantation in an ion implantation chamber, said apparatus comprising:

a housing;

a compression plate coupled to said housing and adapted to engage said semiconductor wafer at its circumferential edge;

a pressure plate, in movable relationship with said compression plate, adapted for movement between a retracted position, in which said compression plate and said pressure plate define a wafer - receiving slot, and a wafer - clamping position, in which said pressure plate clamps said semiconductor wafer firmly against said compression plate;

a pad assembly including a pliable, thermally conductive pad positioned between said pressure plate and said wafer so as to provide thermal conduction therebetween when said pressure plate is in said wafer - clamping position and a pad holder which holds said thermally conductive pad around its periphery and which is coupled to said housing;

a bellows coupled between said housing and said pressure plate, said bellows containing a fluid which, upon application of a predetermined pressure thereto, causes expansion of said bellows and movement of said pressure plate from said retracted position to said wafer - clamping position, said fluid being thermal contact with said pressure plate;

means for applying said predetermined pressure to said fluid when movement of said pressure plate to said wafer - clamping position is desired;

means for cooling said fluid; and

means for retracting said pressure plate to aid retracted position upon removal of said predetermined pressure from said fluid,

whereby thermal energy is transferred from said wafer through said pad and said pressure plate to said fluid.

20. The apparatus as defined in claim 19 wherein said compression plate and said pad assembly are coupled to said housing by a plurality of pins extending through said pad assembly and said compression plate and a plurality of fastener elements coupled to said pins whereby said compression plate and said pad assembly can easily be removed from said apparatus by removal of said fastener elements from said pins.

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